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Amino acid composition of proteins and technological indicators of grain quality of genotypes and varieties of spring soft wheat in northern Kazakhstan

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The purpose of the paper was to carry out a biochemical and technological evaluation of spring soft wheat grain and to determine the total amino acid composition for the selection of the most valuable genotypes with a high content of essential amino acids. This paper presents the results of biochemical and technological studies of the grain and flour of spring soft wheat plants grown in northern Kazakhstan. The research involved 170 genotypes of spring soft wheat from northern Kazakhstan, 16 of which had the highest grain quality. In the grains of the studied samples, the protein content and the number of essential and nonessential amino acids were determined, and the biological value of the protein was evaluated using the amino acid score method. A strong positive correlation was established between phenylalanine and lysine (r = 0.98), and a weak negative relationship was established between protein content and methionine (r = -0.02) and between methionine and lysine (r = -0.17). Based on the obtained data, the most valuable varieties and lines (256/14 and 53/14) with high-quality information about grain, flour, and bread and the most balanced amino acid composition of proteins were selected because these varieties are important for enhancing the nutritional value and overall utility of these wheat varieties in food production and human consumption. The utilization of such genotypes in breeding programs and agricultural practices holds the promise of yielding crops with improved protein quality and nutritional content, ultimately contributing to enhanced food security and dietary health in the region.
Keywords: Soft wheat, quality, correlation, grain quality assessment, Spring soft wheat, Biochemical evaluation, Technological evaluation, Amino acid composition, Grain quality, Northern Kazakhstan, Protein content.

INTRODUCTION

The main areas of agricultural land used for crops in northern Kazakhstan are occupied by grain crops. A large area is used for spring soft wheat crops since the geographical location allows for the growth of high-quality grains of soft wheat varieties. One of the sources of vegetable protein is cereals, the most affordable source of protein. According to Khan (2014), Liu *et al*. (2016), and Zahra *et al*. (2023), the quality of wheat grain is an important factor determining human nutrition and depends not only on varietal characteristics but also on biotic and nonbiotic factors. The nutritional value of food protein depends on its chemical composition, which affects its biological value and digestibility.
One of the most important tasks of breeding is to improve the grain quality of the plants and to perform a comprehensive study of the main technological and biochemical indicators. This can be achieved in more in-depth studies of proteins and amino acid compositions (Nikitenko *et al*., 2015;Shop-modern.ru, 2021; Siddiqi *et al*., 2020; Xiao and Guo, 2022). Amino acids are divided into nonessential (synthesized in the body) and essential (cannot be synthesized in the human body and must come from outside). There are eight amino acids: isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine (Abro *et al*., 2019; Sułek *et al*., 2023).
However, the amount of amino acids may vary depending on the protein content. For example, according to Markevich *et al*. (2013), Khan (2014), and Putyatin *et al*. (2016), lysine and arginine tend to increase as the protein content decreases (Miyagi *et al*.,2023). The balance of the amino acid composition of wheat proteins is influenced by genotype (Akar *et al*., 2019). Wheat protein is rich in glutamic acid and proline, which are the dominant nonessential amino acids. Patterson and Flint (1990) also reported a deficiency of lysine, tryptophan, and methionine in wheat protein.

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Thus, breeders are faced with the task of not only increasing the yield of varieties but also increasing the quantity and quality of protein, improving the amino acid composition, and increasing the proportion of essential amino acids to increase the nutritional value of grain (Pomorova *et al*., 2022; Sharma *et al*., 2020).

The purpose of this work was to carry out a biochemical and technological assessment of spring wheat grain and to determine the total amino acid composition for the selection of the most valuable genotypes with a high content of essential amino acids for further breeding work.

Tasks

- To determine the protein content and amino acid composition of proteins and the level of essential amino acids in the grains of varieties and genotypes of spring soft wheat in northern Kazakhstan. This requires the application of analytical methods. For protein content determination, the Kjeldahl method, a widely recognized and reliable analytical technique, was employed. This method involves the digestion of wheat samples, converting nitrogen content into protein content. The amino acid analysis in this study was conducted using capillary electrophoresis with a 105 M KAPEL capillary electrophoresis system and Elforan software, enabling the precise quantification of individual amino acids in the wheat samples.
- To determine the quality of the grain, flour, and bread of the studied varieties and genotypes (quantity and quality of gluten, grain unit, weight of 1,000 grains, vitreousness, commercial classification, physical properties of dough, baking score);
- To study the correlation between quality indicators (biochemical, technological, and baking characteristics).

The paper is structured as follows: first, we discuss the materials and methods used in the study, followed by the results and their discussion. Finally, we provide conclusions and highlight the significance of our findings for the agricultural and nutritional sectors.

MATERIALS AND METHODS

The objects of the study were the grain and flour of six promising breeding lines and 10 varieties of spring soft wheat (harvested from 2021–2022).

A 3100 laboratory mill (Perten, Sweden) was used to produce wheat grain meal. The flour was obtained by grinding using a CD 1 mill (Chorin, France) and Buhler mill (Germany).

When assessing the quality of the varieties, we determined the protein content (using the Kjeldahl chemical method) and indicators of the physical properties of the grains (the amount of gluten was determined by washing gluten using mechanized devices, and the quality of gluten was determined using a gluten deformation meter (GDM)). The grain unit measurement method involved filling a measuring container with a decreased load from the grain, the weight of 1,000 grains was measured using the weight method, and vitreousness was measured by candling the grain using a directed light flux).

Determination of proteinogenic amino acids was carried out according to the method of determining the mass fraction of amino acids based on capillary electrophoresis using a 105 M KAPEL capillary electrophoresis system with Elforan software.

The amino acid score (protein value index) of the samples was calculated by dividing each amino acid obtained during the ideal protein analysis proposed by the Food and Agricultural Organization (FAO)/World Health Organization (WHO) (Mudarisov *et al*., 2021).

$$AC = \frac{Ax}{A} * 100\%$$

where Ax is the mass fraction of an essential amino acid in the product under study, g/100 g of protein;

A is the mass fraction of an essential amino acid in a reference protein, g/100 g of protein.

An ideal protein is a ratio of essential amino acids that allows the body to easily update certain internal structures (FAO/WHO Committee) (Litwinek *et al*., 2013; Wan *et al*., 2021).

The rheological properties of the dough were determined using a Brabender Farinograph (Germany) (water absorption, valorimetric value) and a Chopin alveograph (France) (dough resilience modulus, the ratio between the elasticity P and the extensibility of the dough L).

The final stage of determining the quality of flour involved evaluating the samples during the trial baking of bread and the overall baking score. A complete organoleptic evaluation of the bread was performed following the methodology of state variety testing, during which the external bread quality properties (surface, shape, crust color, volume, shape stability) and internal properties (porosity, elasticity, crumb color) were evaluated.

The baking classification of the wheat samples was carried out according to the entire studied set of indicators of the physical properties of grain, dough, and baking properties (Fedin, 1988).

The correlation statistical analysis conducted in this study aimed to explore the relationships and associations between various quality indicators of wheat grain, flour, and bread. This analysis provides valuable insights into how different parameters are interconnected and can be crucial for understanding the overall quality of wheat-based products.

The Agros-2.11 software package was used for this correlation analysis. Agros-2.11 is a specialized statistical software widely used in agricultural research for data analysis and interpretation.

RESULTS AND DISCUSSION

The main indicators of grain quality are the grain unit, protein content, and gluten quantity and quality. The protein and gluten contents in the grain, which determine its biological usefulness and nutritional benefits, averaged 15.80 and 33.4%, respectively (Table 1). The average gluten quality was 78 GDM units.

The grain size is an important indicator of quality and was used to determine the milling advantages of grains. In our studies, the grain unit weight of the studied varieties and genotypes varied from 793 g/l (line 221/14) to 826 g/l (line 80/14).

Table 1. Average biochemical and technological indicators of grain quality for selected varieties and lines of spring soft wheat (harvest 2021-2022).

Line, variety	Mass fraction		Gluten quality, GDM unit	Grain unit, g/l	Weight of 1,000 grains, g	Vitreousness, %
	protein, %	gluten, %				
182/14	15.23	32.2	76	823	34.2	71
80/14	15.50	32.2	77	826	35.8	63
53/14	17.43	35.4	75	810	34.4	65
3/14	15.16	36.8	83	823	35.7	70
221/14	16.45	32.8	64	793	34.2	67
256/14	15.12	32.3	72	824	34.7	61
Astana	16.09	35.0	83	819	33.1	64
Akmola 2	16.28	33.7	78	815	34.1	61
Tselinnaya Yubileynaya	15.31	32.1	79	818	33.6	67
Shortandinskaya 95 µl.	15.79	33.8	83	819	37.9	58
Tselina 50	15.16	32.8	87	814	34.0	62
Astana 2	15.63	32.2	83	824	33.6	60
Shortandinskaya 2012	15.02	31.2	76	824	35.8	60
Asyl sapa	16.79	35.5	70	808	30.7	59
Shortandinskaya 2014	15.39	32.1	82	823	34.2	64
Taymas	15.51	33.5	81	813	34.9	61
Min	15.02	31.2	64	793	30.7	58
max	17.43	36.8	87	826	37.9	71
x	15.80	33.4	78	816	34.4	63

Table 2. Physical properties of the doughs of the best wheat varieties and lines, average for 2021-2022.

Line, variety	Dough resilience modulus, W.e.a.	P/L	Water absorption, ml	Valorimetric value, valorimetric units (v.u.)
182/14	404	1.87	76.2	92
80/14	350	1.78	73.5	85
53/14	361	1.05	74.8	81
3/14	404	1.64	74.4	86
221/14	380	1.84	75.4	91
256/14	363	1.03	74.8	83
Astana	365	1.61	74.1	81
Akmola 2	382	1.43	73.4	87
Tselinnaya Yubileynaya	370	1.49	71.8	84
Shortandinskaya 95 µl.	362	1.42	74.9	76
Tselina 50	359	1.20	72.1	79
Astana 2	337	1.01	73.3	79
Shortandinskaya 2012	300	0.96	73.0	87
Asyl sapa	355	0.91	75.1	98
Shortandinskaya 2014	311	0.86	72.7	84
Taymas	281	0.88	73.0	87
min	281	0.86	71.8	76
max	404	1.87	76.2	98
x	355	1.31	73.9	85

The mass of 1,000 grains depends on the genotype, external conditions, and environment during grain formation. The maximum expression of this feature is observed in favorable years, while unfavorable conditions during the formation of grains sharply reduce this indicator (Khlestkina *et al*. 2017). The largest mass of 1,000 grains was observed in the Shortandinskaya 95 ulutshennaya variety (37.9 g).

Table 3. Results of trial laboratory baking of bread made from soft wheat flour (the harvest of 2021-2022).

Line, variety	Volume of bread from 100 g of flour, ml	Shape stability (h/d)	Porosity, score	Overall baking score, points
182/14	668	0.40	3.7	4.4
80/14	670	0.44	4.2	4.6
53/14	718	0.38	3.6	4.3
3/14	663	0.38	4.6	4.6
221/14	680	0.42	4.3	4.5
256/14	735	0.42	4.2	4.4
Astana	668	0.42	4.7	4.7
Akmola 2	660	0.46	4.5	4.8
Tselinnaya Yubileynaya	695	0.47	4.6	4.8
Shortandinskaya 95 µl.	657	0.48	4.3	4.7
Tselina 50	650	0.42	4.7	4.7
Astana 2	685	0.51	4.9	4.7
Shortandinskaya 2012	645	0.42	4.5	4.6
Asyl sapa	633	0.41	4.2	4.8
Shortandinskaya 2014	620	0.44	4.6	4.6
Taymas	650	0.41	4.7	4.6
min	620	0.38	3.6	4.3
max	735	0.51	4.9	4.8
x	670	0.43	4.4	4.6

182/14 53/14 221/14

256/14 80/14 3/14

Akmola 2 Tselinnaya Yubileynaya Asyl sapa

Figure 1. Trial laboratory baking of varieties and lines of spring soft wheat harvested in 2022.

Vitreousness characterizes the structure of the endosperm, indicating its starchy or protein character. Vitreousness in the studied genotypes ranged from 58 to 71%. Lines 182/14 and 3/14 had the most vitreous grains.

Concerning the set of quality indicators, lines 53/14, 221/14, and 256/14 and the Asyl Sapa variety had the highest values. The maximum amount of protein accumulated in the grain of the 53/14 line was 17.43%, with 35.5% gluten and 75 GDM units. Among the studied varieties, we also noted the Asyl Sapa variety, which has a protein content of 16.79%, a gluten content of 35.5%, and a quality of 70 GDM units.

According to the evaluation of the rheological properties of the dough on the alveograph, all studied genotypes of the nursery were included in the strong wheat category. For strong flour, the flour strength index W ranged from 280-500, e.a., and for weak flour, it was less than 180, e.a. The maximum indices of the dough resilience modulus were noted in lines 182/14 and 3/14 (404 W. e.a.) (Table 2). The balance of the alveogram concerning the elasticity to extensibility of the dough (*P/L*) for strong flour should be in the range of 0.7-2.0, which was noted for all studied varieties and lines (Fedin, 1988).

The water absorption of flour determined on the farinograph varied from 71.8 to 76.2 ml and averaged 73.9 ml. The valorimetric values ranged from 76 to 98 v.u. The maximum value was noted for the Asyl Sapa variety (98 v.u.).

According to the results of the trial laboratory baking, bread with a smooth surface and a golden brown crust was obtained. The volume of bread was 620-695 ml, and the shape stability was 0.41-0.51 (the ratio of the height of the hearth loaf to its diameter) (Table 3). The crumb had fine uniform porosity, an elastic structure, and a white color with a yellowish tinge. The overall baking score for the varieties and lines averaged 4.6 points. According to the volume yield of the bread, lines 256/14 (735 ml) and 53/14 (718 ml) and the Tselinnaya Yubileynaya variety (695 ml) had the highest values.

Fig. 1 shows the loaves obtained during the trial laboratory baking of lines and varieties of the 2022 harvest. A maximum baking score of 4.7 points was obtained on line 221/14, and the largest volume of mold-baked bread was observed on line 256/14 (810 ml). The varieties Akmola 2, Tselinnaya Yubileynaya, and Asyl Sapa were characterized by a high baking score of 4.8 points.

Our study allowed us to establish correlations between the studied quality indicators (Table 4). The correlation values were graded according to the Cheddock scale (Koterov *et al.*, 2019).

To determine the relationship between the quality indicators, a correlation analysis was carried out, during which a high dependence was observed between the P/L ratio and the dough resilience modulus (r = 0.73). An average correlation was noted between the grain unit and the quality of gluten (r = 0.56), between the porosity and the quality of gluten (r = 0.54), between the dough resilience modulus and vitreousness (r = 0.58), between the P/L and vitreousness (r = 0.63), between the overall baking score and shape stability (r = 0.56), and between the overall baking score and porosity (r = 0.68).

Table 4. Correlation coefficients between quality indicators of varieties and lines of spring soft wheat.

Indicators	Correlation coefficient, r
P/L and dough resilience modulus	0.73
overall baking score and porosity	0.68
P/L and vitreousness	0.63
dough resilience modulus and vitreousness	0.58
grain unit and gluten quality	0.56
overall baking score and shape stability	0.56
porosity and gluten quality	0.54
porosity and water absorption	-0.70
gluten quality and valorimetric value	-0.67
grain unit and protein	-0.65

For example, our study revealed a substantial positive correlation (r = 0.56) between grain unit and gluten quality, indicating that wheat varieties with higher grain unit measurements tend to exhibit improved gluten quality. This positive relationship suggested that the grain unit, which reflects the density of wheat grains, contributes positively to gluten formation during the breadmaking process (Lavoignat *et al.* 2022; Pourmohammadi *et al.* 2023). Enhanced gluten quality is desirable in wheat-based products because it results in better dough elasticity and overall bread texture.

An average negative relationship was established between the grain unit weight and protein content (r = -0.65), between the gluten quality and the valorimetric value (r = -0.67), and between the shape stability and the gluten content (r = -0.59). A strong negative correlation was obtained between porosity and water absorption (r = -0.70). The remaining indicators were poorly correlated with each other.

To increase the value of grain, it is important not only to consider biochemical and technological indicators but also to study its amino acid composition. For this purpose, studies were conducted during which essential (lysine, phenylalanine, leucine, isoleucine, methionine, valine, threonine) and nonessential (arginine, tyrosine, histidine, proline, serine, alanine, glycine) amino acids were determined. The maximum number of total essential amino acids was found in lines 256/14 (5.40%), 53/14 (5.10%), 125-14 (5.00%) and varieties Akmola 2 (5.13%) and Tselina 50 (5.12%) (Table 5).

To determine the full value condition of the protein, the amino acid score was calculated. According to the WHO data and analysis of published data, if the indicator is higher than or equal to 100, the protein of the product is recognized as the full value and is capable of independently providing the body with all the necessary sets of essential amino acids. If an

essential amino acid in the product has an amino acid score lower than 100, then that amino acid is recognized as limiting, and the protein of the product itself is incomplete (Wan *et al*., 2021; Xiao and Guo, 2022).

After calculating the amino acid score for each essential amino acid, we noted the 256/14 line with the most balanced amino acid composition: lysine, 113%; phenylalanine, 202%; leucine; isoleucine, 120%; methionine, 109%; valine, 206%;

Table 5. Composition of essential amino acids in grain proteins from varieties and genotypes of spring soft wheat.

Genotype, variety	Essential amino acids, %						
	Lysine	Phenylalanine	Leucine and isoleucine	Methionine	Valine	Threonine	Total
3/14	0.47	0.94	1.02	0.45	0.81	0.65	4.34
29/13	0.47	0.89	0.97	0.42	0.80	0.65	4.20
221/14	0.50	1.06	1.15	0.57	0.91	0.72	4.91
182/14	0.52	1.03	1.14	0.54	0.92	0.73	4.88
80/14	0.36	0.72	0.85	0.42	0.63	0.55	3.53
147/14	0.53	1.07	1.13	0.45	0.93	0.76	4.87
53/14	0.56	1.14	1.23	0.42	0.97	0.78	5.10
337/13	0.55	1.10	1.24	0.42	0.05	0.78	4.14
256/14	0.62	1.21	1.32	0.38	1.03	0.84	5.40
125/14	0.55	1.12	1.20	0.41	0.95	0.77	5.00
86/13	0.49	0.90	1.01	0.31	0.79	0.67	4.17
Astana	0.48	0.96	1.10	0.42	0.89	0.71	4.56
Akmola 2	0.49	0.99	1.26	0.63	1.01	0.75	5.13
Tselinnaya Yubileynaya	0.41	0.88	0.99	0.46	0.74	0.66	4.14
Tselina 50	0.44	0.92	1.34	0.73	0.99	0.70	5.12
Astana 2	0.50	0.99	1.09	0.34	0.86	0.73	4.51
Shortandinskaya 2012	0.47	0.94	1.04	0.33	0.82	0.67	4.27
Asyl sapa	0.49	0.96	1.14	0.39	0.89	0.74	4.61
Shortandinskaya 2014	0.43	0.85	1.00	0.48	0.73	0.65	4.14
Taymas	0.43	0.89	1.04	0.48	0.74	0.67	4.25
min	0.36	0.72	0.85	0.31	0.05	0.55	3.53
max	0.62	1.21	1.34	0.73	1.03	0.84	5.40
x	0.49	0.98	1.11	0.45	0.82	0.71	4.56

Table 6. Amino acid scores for essential amino acids in spring soft wheat varieties and lines.

Genotype, variety	Essential amino acids, %						
	Lysine	Phenylalanine	Leucine and isoleucine	Methionine	Valine	Threonine	Total
3/14	85	157	93	129	162	163	4.34
29/13	85	148	88	120	160	163	4.20
221/14	91	177	105	163	182	180	4.91
182/14	95	172	104	154	184	183	4.88
80/14	65	120	77	120	126	138	3.53
147/14	96	178	103	129	186	190	4.87
53/14	102	190	112	120	194	195	5.10
337/13	100	183	113	120	10	195	4.14
256/14	113	202	120	109	206	210	5.40
125/14	100	187	109	117	190	193	5.00
86/13	89	150	92	89	158	168	4.17
Astana	87	160	100	120	178	178	4.56
Akmola 2	89	165	115	180	202	188	5.13
Tselinnaya Yubileynaya	75	147	90	131	148	165	4.14
Tselina 50	80	153	122	209	198	175	5.12
Astana 2	91	165	99	97	172	183	4.51
Shortandinskaya 2012	85	157	95	94	164	168	4.27
Asyl sapa	89	160	104	111	178	185	4.61
Shortandinskaya 2014	78	142	91	137	146	163	4.14
Taymas	78	148	95	137	148	168	4.25
min	65	120	77	89	10	138	3.53
max	113	202	122	209	206	210	5.40
x	89	163	101	129	164	178	4.56

Table 7. Correlation matrix showing relationships between protein content and essential amino acids in spring wheat grain.

Genotype, variety	Essential amino acids, %						
	Lysine	Phenylalanine	Leucine and isoleucine	Methionine	Valine	Threonine	Total
3/14	85	157	93	129	162	163	4.34
29/13	85	148	88	120	160	163	4.20
221/14	91	177	105	163	182	180	4.91
182/14	95	172	104	154	184	183	4.88
80/14	65	120	77	120	126	138	3.53
147/14	96	178	103	129	186	190	4.87
53/14	102	190	112	120	194	195	5.10
337/13	100	183	113	120	10	195	4.14
256/14	113	202	120	109	206	210	5.40
125/14	100	187	109	117	190	193	5.00
86/13	89	150	92	89	158	168	4.17
Astana	87	160	100	120	178	178	4.56
Akmola 2	89	165	115	180	202	188	5.13
Tselinnaya Yubileynaya	75	147	90	131	148	165	4.14
Tselina 50	80	153	122	209	198	175	5.12
Astana 2	91	165	99	97	172	183	4.51
Shortandinskaya 2012	85	157	95	94	164	168	4.27
Asyl sapa	89	160	104	111	178	185	4.61
Shortandinskaya 2014	78	142	91	137	146	163	4.14
Taymas	78	148	95	137	148	168	4.25
min	65	120	77	89	10	138	3.53
max	113	202	122	209	206	210	5.40
x	89	163	101	129	164	178	4.56

	Protein	Lysine	Phenylalanine	Leucine and isoleucine	Methionine	Valine	Threonine
Protein	-						
Lysine	0.29	-					
Phenylalanine	0.33	0.98	-				
Leucine and isoleucine	0.25	0.72	0.76	-			
Methionine	-0.02	-0.17	-0.07	0.44	-		
Valine	0.32	0.80	0.83	0.96	0.33	-	
Threonine	0.36	0.93	0.94	0.85	0.01	0.89	-

and threonine, 210% (Table 6). The content of lysine and a complex of other amino acids was notable in the following lines: 53/14 (102%), 337/13 (100%), and 125/14 (100%).

A well-balanced amino acid profile ensures that all essential amino acids are present in adequate quantities, enhancing the overall nutritional value of the protein (Elango, 2023). Varieties and genotypes with such balanced profiles contribute to the synthesis of complete and high-quality proteins.

The content of essential amino acids, including lysine, threonine, methionine, and tryptophan, is pivotal for the nutritional quality of wheat grains. These amino acids are indispensable for human health, as they cannot be synthesized by the body and must be obtained through dietary sources. Wheat varieties and genotypes with higher concentrations of essential amino acids hold promise as sources of high-quality protein for human consumption, particularly in regions where wheat is a dietary staple (Kaur *et al.* 2023).

We established that lysine and methionine are the limiting amino acids in wheat grain. The correlation between the protein content and all the analyzed essential amino acids was calculated (Table 7).

A very high correlation was observed between the indicators of lysine and phenylalanine (r = 0.98) and leucine, isoleucine, and valine (r = 0.96). An inverse (negative) relationship was observed between methionine and protein (r = -0.02), between methionine and lysine (r = -0.17), and between methionine and phenylalanine (r = -0.07).

Conclusion: As a result of our study, we selected the most valuable lines, 53/14, 221/14, and 256/14, and the Asyl Sapa variety, which had high-quality indicators of grain, flour (182/14, 3/14), and bread (256/14, 53/14), respectively. The most balanced amino acid compositions of proteins were observed in lines 256/14 (5.40%), 53/14 (5.10%), and 125/14 (5.00%), as well as in the varieties Akmola 2 (5.13%) and Tselina 50 (5.12%).

A strong correlation was established between the P/L ratio and the dough resilience modulus (r = 0.73). A high correlation was found between lysine and phenylalanine (r = 0.98) and between leucine and isoleucine and valine (r = 0.96).

In our studies, lysine and methionine were the limiting amino acids in wheat grain. The results of this study have practical implications for both wheat breeding and nutritional improvement. The identification of wheat varieties and genotypes with superior amino acid compositions offers a clear path for enhancing the nutritional quality of wheat grain and its derived products. This has direct relevance for addressing nutritional deficiencies in regions where wheat is a primary dietary staple.

These findings can guide the selection and development of new wheat breeding cultivars with improved amino acid profiles.

In conclusion, while our study focused on evaluating the grain quality of specific wheat genotypes and varieties, it is essential to recognize the significant role played by environmental factors in shaping these quality parameters. Understanding these interactions between genetics and the environment is vital for both wheat breeders and farmers, as they allow for the selection and cultivation of varieties that are better suited to specific ecological conditions, ultimately contributing to more stable and reliable wheat production in various regions.

Future research directions in this domain could focus on the development of molecular breeding techniques to expedite the incorporation of desirable amino acid traits into wheat varieties. Additionally, investigating the broader effects of improved amino acid compositions on wheat resistance to pests, diseases, and environmental stressors could yield insights into the overall resilience and productivity of crops.

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